Basaltic melts in olivine phenocrysts from alkaline pumice of Southern Primorye

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A large intraplate volcanic province was formed in the Late Cenozoic within Central and Eastern Asia. Subalkaline and alkaline magmatism is mainly typical for it. Acid magmatic rocks are a rare exception. In the far eastern part of the province, they are related only to the formation of the large Pektusan volcano located at the boundary between China and Northern Korea and composed of alkaline trachyte and rhyolite. The presence of such a volcano in this province is not only a large geological problem it also determines the high volcanic danger in the region as well. In particular, its historical eruption 969 ± 20 AD was accompanied by an outburst of a huge mass of pyroclastic products, which reached the Islands of Japan.

Based on the study of mineral inclusions we consider the peculiarities of the composition of a melt registered in olivine from alkaline pumices of one of the Pektusan volcano eruptions and estimate the mechanisms that could result in its catastrophic eruptions.

The studied pumices produced by the Pektusan volcano were collected in the territory of Southern Primorye, in the Tyumen-Ula River area. The Pektusan volcano is composed of lavas and pyroclastic rocks of trachyte–comendite–rhyolite composition intruded by volcanic necks and dykes of alkaline basalt, trachybasalt, and trachyandesite. According to the geochronological data, the formation of the volcano proceeded over >3 Ma. Alkaline pumices were removed by the Tyumen-Ula River starting close to the Pektusan volcano to the Sea of Japan and later dispersed by sea currents along the coast.

Pumices are composed of light-grey glass with a refractive index of 1.506 ± 0.002 and a small portion (2 to 3 vol%) of phenocrysts of sanidine, ferrohedenbergite, magnetite, olivine, apatite, ilmenite, zircon, and chevkinite. According to the chemical composition, pumices correspond to trachyrhyodacite. The total concentration of alkalis in them reaches up to 9.5 mass%, with an insignificant prevalence of sodium over potassium. Pumices are characterized by high concentrations of niobium, zirconium, and REE). These pumices are unusual, since olivine in them is magnesium-rich with the composition of Fo74 to Fo79. It is characterized by a high CaO concentration (up to 0.22 mass%) as well.

Coexisting primary melt, crystalline, and fluid inclusions were studied in olivine phenocrysts. Crystalline inclusions in olivine comprise chrome-spinellid, titanomagnetite, picroilmenite, and clinopyroxene (?). Chrome-spinellid inclusions contain 8.8 to 16.7 mass% Cr_2O_3, 8.5 to 12.0 mass% Al_2O_3, and 7 to 8 mass% MgO at a FeO concentration of 48 to 57 mass%. The studied chrome-spinellids are characterized by an extremely high TiO_2 concentration reaching 10.5 to 14.0 mass%, which allowed us to characterize them as titanium chrome-spinellids. Titano-magnetite contain 65 to 70 mass% FeO and 13 mass% TiO_2. The chemical composition of ilmenite is characterized by very high concentrations of MgO (up to 9.6 mass%), which corresponds to the composition of picroilmenite. In addition to ore minerals, crystalline inclusions comprised an unusual silicate phase with the composition close to clinopyroxene. This phase is characterized by extremely high concentrations of TiO_2 and P_2O_5 (6 and 4 mass%, respectively). Thus, the mineral association registered in olivine is not typical for trachyrhyodacite.

Primary melt inclusions in olivine are located irregularly and have a shape close to oval and sizes from 30 to 150 μm. They are usually partly crystallized and contain residual glass,

daughter minerals and a gaseous phase. Residual (not heated) glasses in melt inclusions contain high concentrations of alkalis (Na_2O + K_2O) up to 5.2 mass%, CaO up to 5 mass%, P_2O_5 up to 1.3 mass% at concentrations of 60 to 64 mass% SiO_2 and 21 mass% Al_2O_3. As a whole, the compositions of residual glasses from melt inclusions plot on the andesite field in the classification SiO_2 – (Na_2O + K_2O) diagram. Daughter minerals of melt inclusions comprise augite, ilmenite, titanium chrome-spinellid and apatite. As a whole, the set of daughter minerals in melt inclusions is close to the mineral association registered in olivine as crystalline inclusions. According to our thermometric data, the melt inclusions homogenize at 1040 to 1230 ºC.

In addition, several two-phase fluid inclusions containing liquid and gaseous carbon dioxide were registered in two olivine phenocrysts. Homogenization into the liquid phase occurs at 29.0 °C, which provides evidence a high density in the inclusions (0.63 g/cm^3). The pressure calculated from PVT data of CO_2 in a temperature interval of 1040 to 1230 °C is 2600 to 3000 bar, which corresponds to a depth of 10 to 13 km.

Examination of the glasses under an electron microscope allowed us to reveal a significant difference between their composition and that of the pumice. The chemical composition of homogeneous glasses from melt inclusions corresponds to the composition of basalt and is characterized by high concentrations of 2.2 to 3.5 mass% TiO_2 and up to 0.7 mass% P_2O_5 at a SiO_2 content of 44 to 52 mass% and 12 to 18 mass% Al_2O_3. The concentration of alkalis (Na_2O + K_2O) in the melts is quite high as well (4.0 to 6.6 mass%) with a strong prevalence of Na_2O over K_2O. The comparison of the compositions of the melt inclusions and those of the alkali basalts of Pektusan volcano show their obvious similarities (Table 1). Similarly to the studied melts, alkaline basalts are characterized by high TiO_2 concentrations. As was mentioned above, the formation of the Pektusan volcano with alkaline pumices of Primorye as products occurred in intracontinental conditions. The studied peculiarities of the composition of glasses from homogenized melt inclusions in olivine demonstrate clear characteristics of intraplate magmas, particularly the high concentrations of TiO_2, P_2O_5, and K_2O. Thus, the results of the study of inclusions allow us to consider that olivine observed in alkaline pumices as phenocrysts is a non-equilibrium mineral and most likely a crystalline fragment of the basalts. The identity of the composition of glasses from melt inclusions in olivine from basalts supports this assumption. The presence of high-titanium and high-magnesium minerals, namely titanium chrome-spinellid and picroilmenite in olivine, is quite consistent with the suggested assumption as well.

This allows us to assume participation of the processes of mixing of melts with contrasting compositions in the formation of alkaline pumices. Portions of basaltic magma together with olivine crystals contained in it were incorporated in the mobile acid melt, which provided degassing and foaming of magma. An increase in pressure in the magmatic chamber could catalyze the explosive eruption, which resulted in an outburst of trachyte pumices containing phenocrysts of xenogenic olivine. Thus, pumices of Primorye are most likely hybrid rocks formed as a result of mixing of acid and basic magmas.

	1	2	3
SiO_2	43.89	47.32	46.77
TiO_2	3.55	2.67	3.06
Al_2O_3	12.36	13.85	14.78
FeO	18.92	13.62	12.81
MnO	0.32	0.17	0.21
MgO	6.47	7.79	4.51
CaO	7.7	7.16	6.96
Na_2O	3.03	3.07	3.71
K_2O	1.41	1.55	2.18
P_2O_5	0.79	0.59	0.64
Cl	0.03	0.03	-
S	0.13	0.08	-
H_2O	-	-	0.48
Total	98.6	97.9	99.91*

Table 1. Chemical composition of glass in melt inclusions contained in olivine from pumice from Primoye and basalt from Pektusan volcano
Note: 1, 2 – glasses in melt inclusions; 3 – basalt (the analytical total is reported with regard for 3.80 mass% LOI (Sakhno, 2007)).

REFERENCES

Sakhno, V.G. (2007). *Dokl. Ros. Akad. Nauk* 417 (3): 528-534.